

Diffusivity Measured as a Function of Concentration

Optical diagnostic techniques have become an integral part of many measurements in industrial and research laboratories. Many types of interferometers and their phase-shifted versions have been used to measure optical wave fronts for lens testing and combustion and fluid flow diagnostics. One such instrument is the point diffraction interferometer (PDI), which is considered to be robust because it has a common-path design. However, the PDI is difficult to align and has limited measurement range for liquid phase applications. Interferometry and schlieren techniques have been widely used for many years for gas flow visualization.

For the first time, researchers at the NASA Glenn Research Center have been able to use a compact common path interferometer (CPI) to measure the concentration-dependent diffusion coefficient of two miscible liquids that diffuse into each other. The CPI is an optical technique that can be used to measure changes in the gradient of the refractive index of transparent materials. It is a shearing interferometer that shares the same optical path from a laser light source to the final imaging plane. It uses a Wollaston prism polarizer in combination with an analyzer (crystalline quartz retardation plate) instead of a PDI unit. The advantage of using the CPI over other optical techniques is that it can make quantitative measurements in liquids with large index of refraction variations, as often is the case in interface dynamics studies. This can be accomplished simply by using different polarizers for each particular experimental condition.

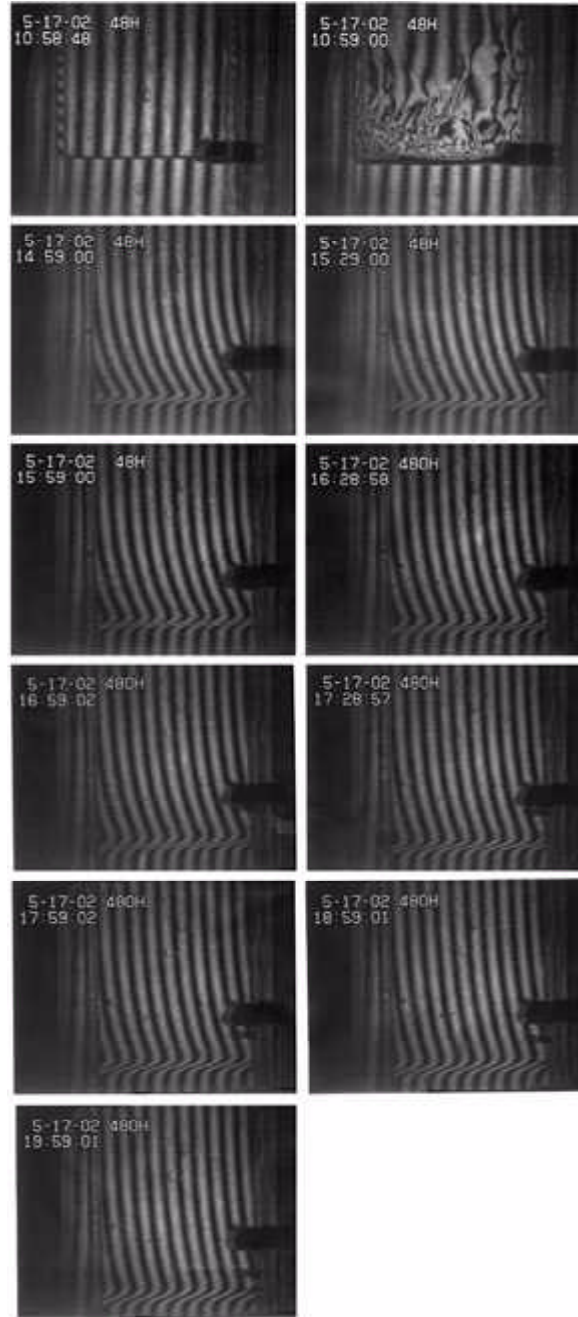
In previous work, we showed (refs. 1 to 3) that the instrument can easily measure the diffusion coefficient of miscible liquid pairs. Miscible fluid flows are important in enhanced oil recovery, fixed bed regeneration, hydrology, and filtration. The dynamics of miscible interfaces is an active area of research that has been identified to benefit from experimentation in reduced gravity, and the diffusivity is an important physical property in such experiments. Its measurement is required to determine the ranges for experimental parameters, such as the displacement speed, so that the effects of convection and diffusion are in optimal balance.

The molecular diffusion coefficient of liquids can be determined using physical relations between changes in the optical path length and liquid phase properties. Data obtained through the use of the CPI and compared with similar results from other techniques have demonstrated that the instrument is far superior for measuring the diffusivity of miscible liquids while keeping the system very compact and robust (ref. 4). Because of its compactness and ease of use, the CPI has been adopted for use in studies of interface dynamics as well as other diffusion-controlled process applications (ref. 4). This progress will permit the optimal design of experiments in microgravity that can quantitatively answer basic science questions about mass and thermal diffusion and their effects in transport processes. This instrument is a spinoff of a diagnostic development for microgravity fluid physics experiments at Glenn that used existing optics and electronics in

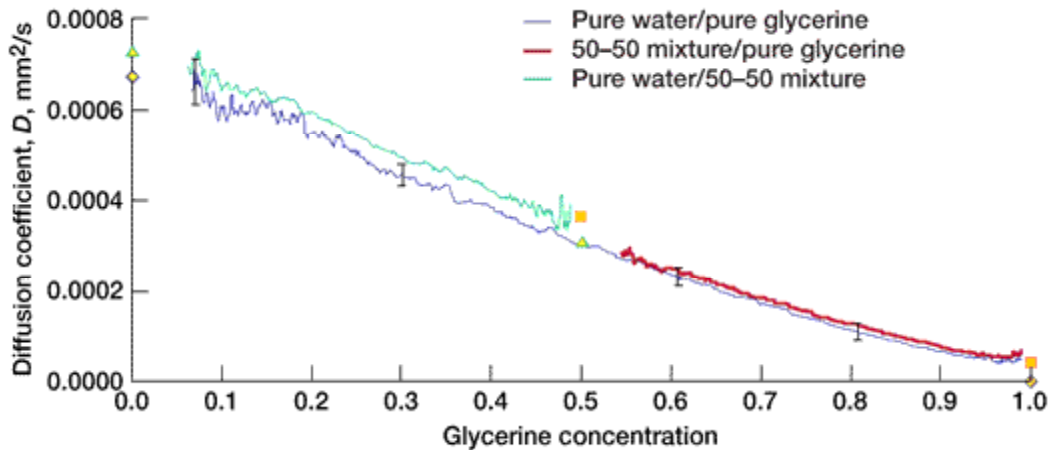
the Fluid Physics laboratory for feasibility studies. Several scientists have expressed their interest in using this instrument for their research.

In the course of our use of this instrument, we realized that not all the fluids have a constant diffusion coefficient. The diffusivity of some liquid pairs change with concentration and time. This prompted us to search for a general method to process the raw data obtained using the CPI to measure the diffusion coefficient as a function of the local concentration. A general method was subsequently developed and reported (ref. 5).

The new data processing approach was applied to measure the concentration-dependent diffusivity of a pair of miscible fluids. The mathematical model of the new approach in using the CPI is discussed in references 3 and 5, and sample results are shown in the figures. The diffusivity results are in excellent agreement with available data. The physical properties measured are in support of a space experiment which is planned (ref. 4) to be conducted in the International Space Station in 2005.



Interferograms representing the evolution of the concentration gradient at a water-glycerin interface. (a) Glycerin is present before water is added to the top. The horizontal dark fat line in all the panels is a fixed reference mark on the cell. The remaining panels show the evolution of the fringes at various times. (b) 0 min. (c) 240 min. (d) 270 min. (e) 300 min. (f) 330 min. (g) 360 min. (h) 420 min. (i) 480 min. (j) 540 min. (k) 600 min.



Diffusivity of water-glycerin system that represents the diffusion coefficient as a function of glycerin concentration. This figure also shows the diffusion coefficients obtained for the diffusion of pure water placed on top of a 50-50 mixture of water and glycerin and for the diffusion of a 50-50 mixture of water and glycerin placed on top of pure glycerin. The agreement of the measured diffusion coefficients for the three experiments is very good, indicating the robustness of the measurement technique. The filled symbols represent diffusivity at the endpoints where the concentration gradient contribution to the diffusivity is very small.

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